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Capacitive Sensors Realized on Flexible Substrates

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Abstract:
The article presents design and realization results of capacitive sensors realized on flexible substrates. Presented planar capacitive sensors were realized by standard polymer and ink-jet printing technologies at two different polymer substrates. Developed flexible planar capacitive sensors can be used as a standard mechanical keyboard replacement by journalists (touch-typists) where low response time is required, or e.g. in medical environment, where high level of hygiene is required. Fully configurable design and high level of flexibility predestine these capacitive sensors to be used in almost every application to replace mechanical switch wear out by almost unlimited lifetime.

INTRODUCTION

Progressive development of modern technologies (e.g. Internet of Things, wearable electronics, robotics, automatization ...) requires a huge amount of sensor devices. There are many criteria for sensors, but when it comes to consumer electronics, the most sensors are compared from the cost and reliability views. For this reason, most of the consumer electronics manufacturers started to uses non-mechanical control components for devices control. Capacitive sensors are one of the most commonly used sensors for human-machine interaction [1].

The development of planar technologies has made it possible to minimize the dimensions of standard industrial sensors [2, 3, 4], allowing them to be used in applications that have been limited by the space available for sensing elements (safety and security systems, manufacturing process control, etc.) [5, 6]. In this paper we present capacitive sensors realized on flexible substrates that allow them to be used in different applications [7], e.g. as liquid level sensors or proximity (touch) sensors (Fig. 1).

Flexible substrates offer many advantages in compare to PCB or LTCC technology, such as low cost, ease of production and processing, flexibility and foil shaping in a defined application, and no expensive tools are needed for substrate processing and treatment.

For the purpose of presenting the realization and application of polymer film and inkjet printing technologies on flexible substrates, we have realized a fully functional prototype of touch keyboard as a replacement for a standard mechanical keyboard (Fig. 2) that offers a number of advantages such as flexibility, plasticity, mechanically unlimited lifetime, simple expandability and configurability, reduced response time in compare to mechanical buttons.

Submitted design solution will allow using this flexible touch keyboard in a variety of industrial applications, as a service and control of production lines or product quality sensors.

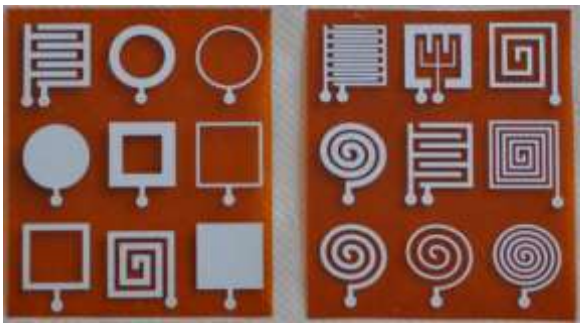

Fig. 1: Example of tested capacitive sensors for finger´s touch sensing realized on flexible Kapton HN foil.

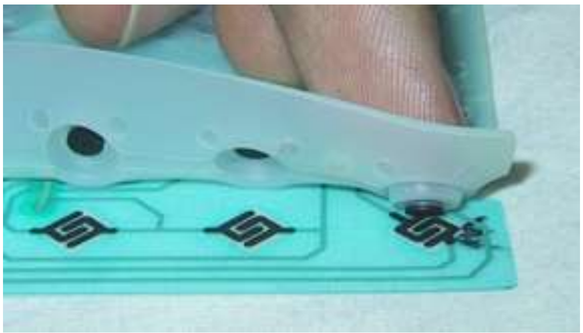

Fig. 2: Standard membrane keyboard.

Based on exactly defined application requirements, such a flexible touch keyboard can be designed and configured for touch or proximity detection, and various sliders for different level intensity setting can be added for precision process control. This specific keyboard can be than mounted into control panel with minimum space available. The advantage of proposed

touch keyboard is that all integrated circuits required for keyboard functionality can be mounted directly on foil substrate, so no additional space is required.
Flexible capacitive keyboards presented in the paper were realized by standard polymer thick film and inkjet printing technologies at two different polymer substrates.

THEORY OF CAPACITIVE SENSOR OPERATION

Capacitive sensor´s operation is based on interaction of every object that reaches electrical field created by this sensor (Fig. 3). Depending on sensed object parameters (relative permittivity, dimensions, etc.) and distance between capacitive sensor´s sensing (active) electrode and sensed object, measured capacity is being increased [8].

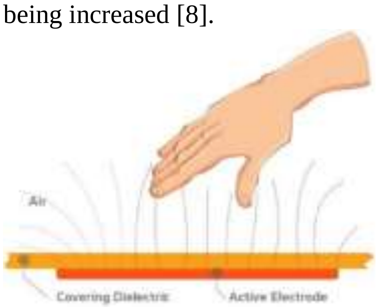

Fig. 3: Capacitive sensor´s operation. [8]

CAPACITIVE SENSORS LAYOUT AND DESIGN SPECIFICATION

Based on our previous experiments, as a planar capacitive sensor layout we chose fully filled circle shape with 6 mm diameter. This sensor´s shape and diameter showed the best performance and sufficient sensing range for touch sensing. Final sensor layout uses 9 these sensors in 3x3 matrix configuration (Fig. 4). The distance between single sensors is 15 mm and the whole sensor matrix is smaller than 50 mm by 50 mm. Because of sequential switching of every sensor (only one of the nine sensors is active in the same time) and no additional electronic system is present on the substrate, no shielding or grounding precautions to limit parasitic effects of capacitive sensing were used.

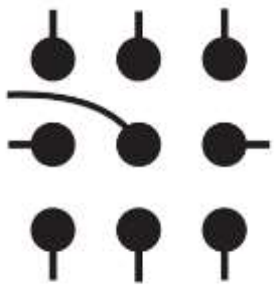

Fig. 4: Realized capacitive sensor matrix.

SENSORS FABRICATION

For our experiments we used ink-jet printing and polymer thick film technologies suitable for realization of flexible capacitive sensors. As substrates, PI Kapton HN from DuPont and PET Mylar A FI 13010 from Dr. Dietrich Müller GmbH film foils with roughness and wettability parameters listed in Tab. 1 [9] were used. Silver based UTDAgIJ nano-ink with parameters listed in Tab. 2 [10] from UT Dots, Inc. for ink-jet printing technology and silver based conductive paste Electra D´Or ED2000 with parameters listed in Tab. 3 [11] for polymer technology were used for printing on these substrates. For the purpose of determining number of printed layers impact on capacitive sensor performance [12], one, two and three layers were printed by ink-jet printing technology on both substrates. Because both nano-ink and polymer paste cannot be directly soldered [13], we had to use electrically conductive adhesive.

Tab. 1: Chosen roughness and wettability parameters of substrates used for capacitive sensor realization [9]

	DuPont™ Kapton® HN	PET Mylar® A FI 13010
Roughness R_a [μm]	0.044	0.046
Contact angle [°]	60.585	78.57
Drop volume [μl]	12.88	13.58

Tab. 2: Parameters of UTDAgIJ nano-ink used for capacitive sensors realization [10]

	UTDAgIJ
Manufacturer	UT Dots, Inc.
Percentage of silver [%]	25-60
Viscosity [mPas]	1-30
Particle size in diameter [nm]	10
Electrical resistivity [Ω.cm]	$(3-10)\times10^{-6}$
Recommended sintering conditions	120-300°C

Tab. 3: Parameters of ED2000 polymer conductive paste used for capacitive sensor realization [11]

	ED2000
Manufacturer	Electra
Resistivity at 15 μm thickness [mΩ]	30-35
Resolution of tracks and spaces [μm]	250
Recommended sintering conditions	150-160°C

CAPACITIVE SENSING SYSTEM

Realized flexible capacitive sensors were characterized by FDC2214 capacitance to digital evaluation board (Fig. 5) from Texas Instruments, that offers noise immune testing and very precise, up to 21 bits sensing resolution. Standard conversion time of this converter is 16.25 ms that allows using this chip even in the capacitive touch keyboard application [14].

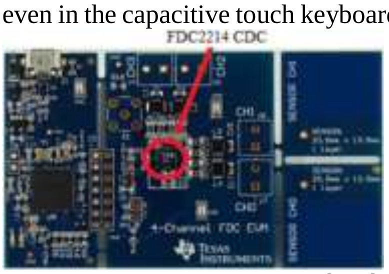

Fig. 5: FDC2214 capacitance to digital evaluation board from Texas Instruments used for characterization of realized capacitive sensors. [14]

Measurements were realized by gradual approaching of human finger model to the sensor active electrode (Fig. 6). Sensing distance was defined as a distance when sensor´s capacitance increased for value 0.2 pF. After that, characteristic of the sensor for touch application was measured.

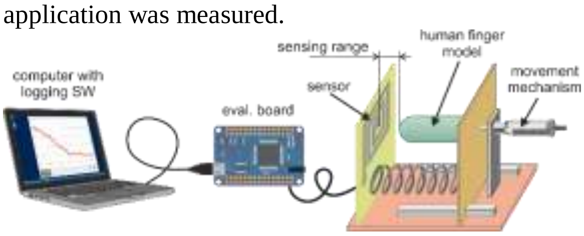

Fig. 6: Principle of characterization of realized sensors.

RESULTS AND DISCUSSION

Realized capacitive sensors by standard polymer thick film and ink-jet printing technologies are shown at Fig. 7 and Fig. 8, respectively. Measured characteristics of capacitive sensors (measured capacitance change in dependence of sensing electrode and finger distance) realized by ink- jet printing technology are presented at Fig. 9 and Fig. 10 (printed one layer at Kapton PI or Mylar PET, respectively), Fig. 11 and Fig. 12 (printed two layers at Kapton PI or Mylar PET, respectively). Measured results of ink-jet printed (three layers) and polymer thick film technology printed capacitive sensors realized on Kapton PI and Mylar PET substrates are presented at Fig. 13.

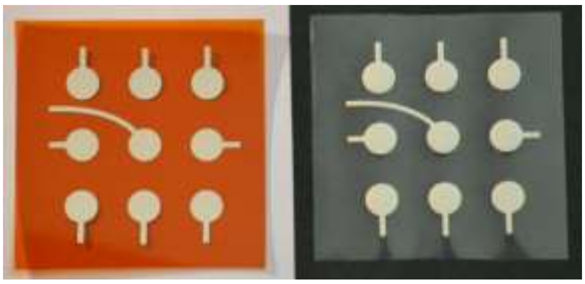

Fig. 7: Capacitive sensors realized by polymer technology. Left - DuPont™ Kapton® HN foil, right - PET Mylar® A FI 13010 foil.

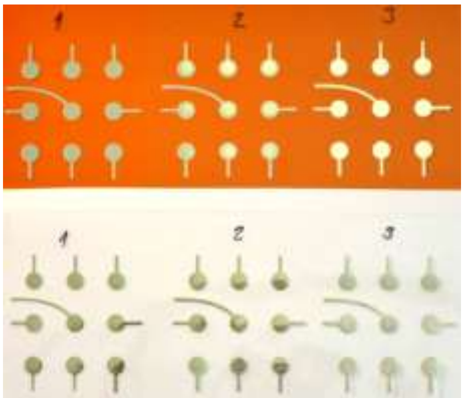

Fig. 8: Capacitive sensors realized by ink-jet printing technology. Up - DuPont™ Kapton® HN foil, down - PET Mylar® A FI 13010 foil.

Measurements showed (Fig. 9, Fig. 10, Fig. 11 and Fig. 12) that sensors printed with just single layer or two layers by ink-jet printing technology are not suitable to be used as capacitive sensors because of significant difference of sensor´s electrode parameters not only between substrates, but also between every sensor´s electrode at one substrate. This difference is caused by different roughness and wettability of used substrates (Tab. 1) that causes inhomogeneity of printed layer (thickness of printed layer is about 200 nm). Printing at least three layers is required to achieve homogeneous sensor structure and repeatability of sensor´s electrode parameters that is more time consuming (significantly for use in industrial applications requiring a huge amount such a sensors) in comparison with standard polymer thick film technology.

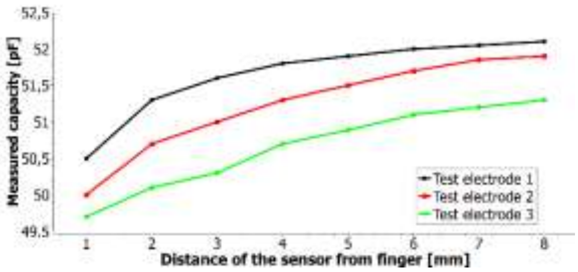

Fig. 9: Measured results of ink-jet printed, single layer capacitive sensors realized on Kapton PI substrate.

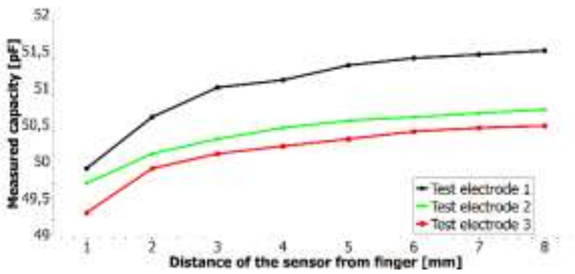

Fig. 10: Measured results of ink-jet printed, single layer capacitive sensors realized on Mylar PET substrate.

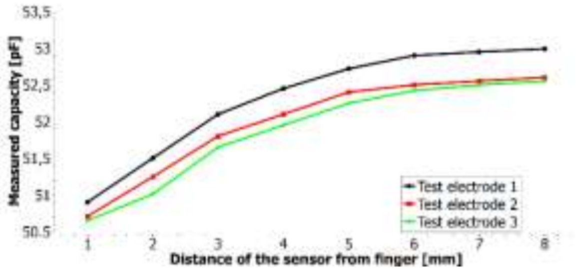

Fig. 11: Measured results of ink-jet printed, two layers capacitive sensors realized on Kapton PI substrate.

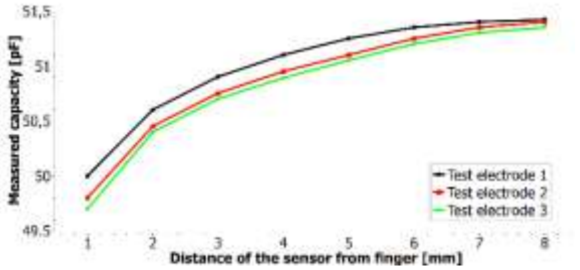

Fig. 12: Measured results of ink-jet printed, two layers capacitive sensors realized on Mylar PET substrate.

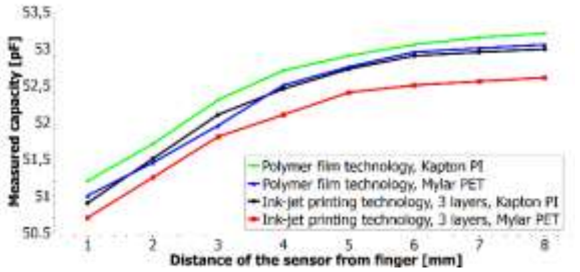

Fig. 13: Measured results of ink-jet printed, three layers and polymer thick film technology printed capacitive sensors realized on Kapton PI and Mylar PET substrates.

It can be seen at Fig. 13, that realised sensors has the best sensitivity in the range from 1 mm to 4 mm, then capacitance changes very slowly. Even with no additional shielding or grounding, sensor was able to detect the presence of the finger at the 8 mm distance. Such a sensing distance is satisfying for capacitive touch sensor application.

Sensors realized by ink-jet printing technology (three layers) showed very similar performance as sensors printed by standard polymer thick film technology. As it was mentioned before, this is caused by different foil roughness and inhomogeneity of silver layer.

Measurements showed that both used substrates are suitable for capacitive sensor application. Especially in touch sensor application, there was measured almost no difference in capacitive sensors parameters.

CONCLUSION

In this paper, the comparative analyse of capacitive sensor´s performance realized by ink-jet printing and standard polymer thick film technologies at flexible Kapton PI and Mylar PET substrates is presented. It was investigated that printing only one or two layers of capacitive sensors by ink-jet printing technology is not sufficient to achieve repetitive performance of sensor electrodes at the same substrate. For this reason, printing at least three layers is required, that is more time consuming in comparison with standard polymer thick film technology. Capacitive sensors realized by standard polymer thick film technology showed very similar performance to three layers ink-jet printed sensors at same substrate. Sensitivity has the same value for all nine electrodes.

Both Kapton PI and Mylar PET substrates showed very stable behaviour for use as capacitive touch sensor substrates. Cheaper Mylar PET substrate is reasonable choice for capacitive sensor manufacturing. Realized capacitive flexible touch matrix is suitable as standard rigid PCB replacement. With sensing electrode´s diameter of only 6 mm we achieved 8 mm sensing distance without additional shielding or grounding precautions. Developed flexible capacitive sensor with response time of only 16.25 ms can be used as a standard mechanical keyboard replacement.

This paper offers opportunities of nonstandard realization of capacitive sensor based on organic electronics. Realized planar capacitive touch sensors have very simple construction, they are reliable and offer very small response time.

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